Orbiting Wide-angle Light-collectors (OWL)

System Engineering
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Conclusions

1. This instrument can meet its design requirements.
2. There are engineering challenges:
   - a. Mass
   - b. Dimensions
   - c. Mechanisms
   - d. Number of detectors
   - e. Method to monitor clouds along view path
3. Two instruments on separate spacecraft

Top Level Requirements

1. 1000 km equatorial orbit
2. Minimum View Aperture = 1*10^12 meters squared steradians
3. Telescope with 22.5 degree Half Field of View and seven meter primary mirror diameter
4. Three year lifetime (5 year goal)
5. Ground pixel size 1000 x 1000 meters
6. 500,000 photo multiplier tube pixels

Instrument Trades

The ISAL team looked at several different concepts for the instrument design. These trade studies included:

1. Different concepts for the primary mirror
2. Deployable versus fixed focal plane
3. Focal plane cooling and impact on integration and test
4. Mass and power reduction where possible
5. Impact on science of possible S/C rolls

Orbit Highlights

1. 1000 km equatorial orbit

2. 105 minutes orbit period

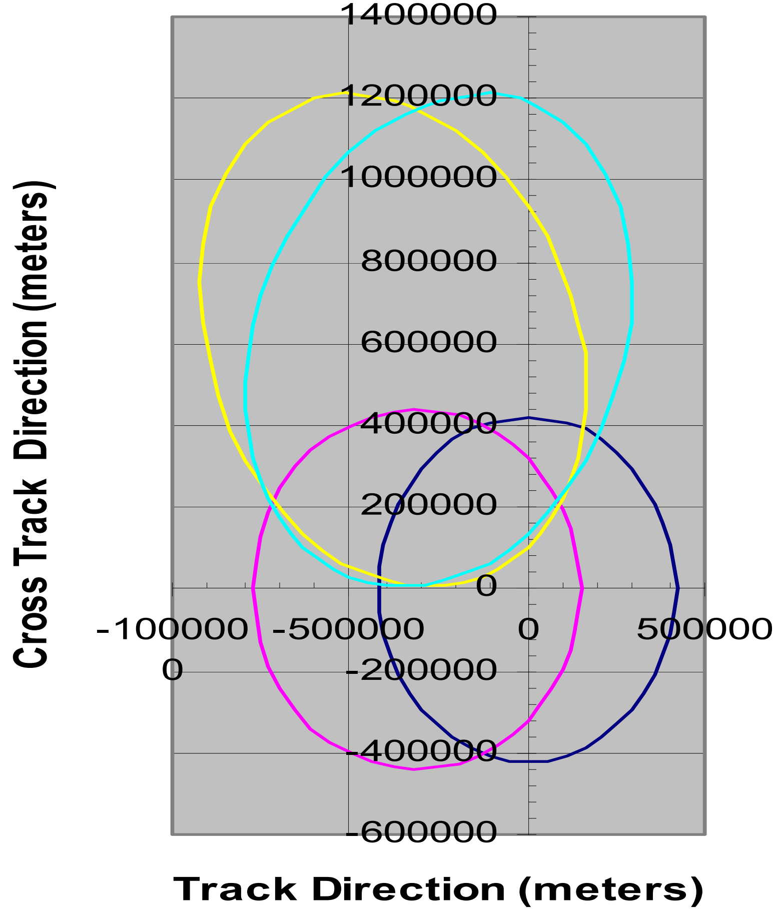
3. Orbital velocity 7400 meters per second

4. Ground track velocity 6400 meters per second

5. Two spacecraft separated by about 500,000 meters
In track direction

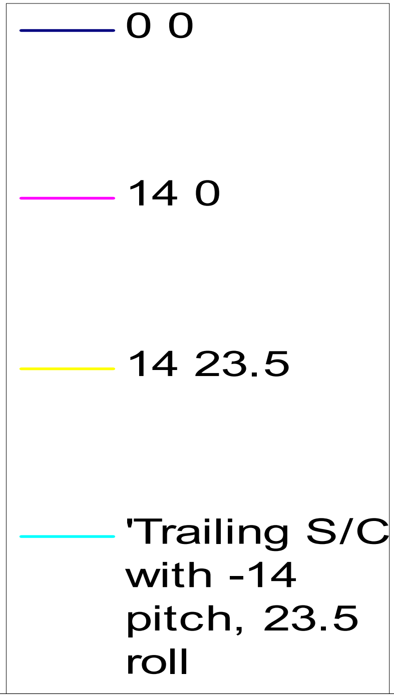
Instrument Footprint

OWL Footprint vs Pitch and Roll



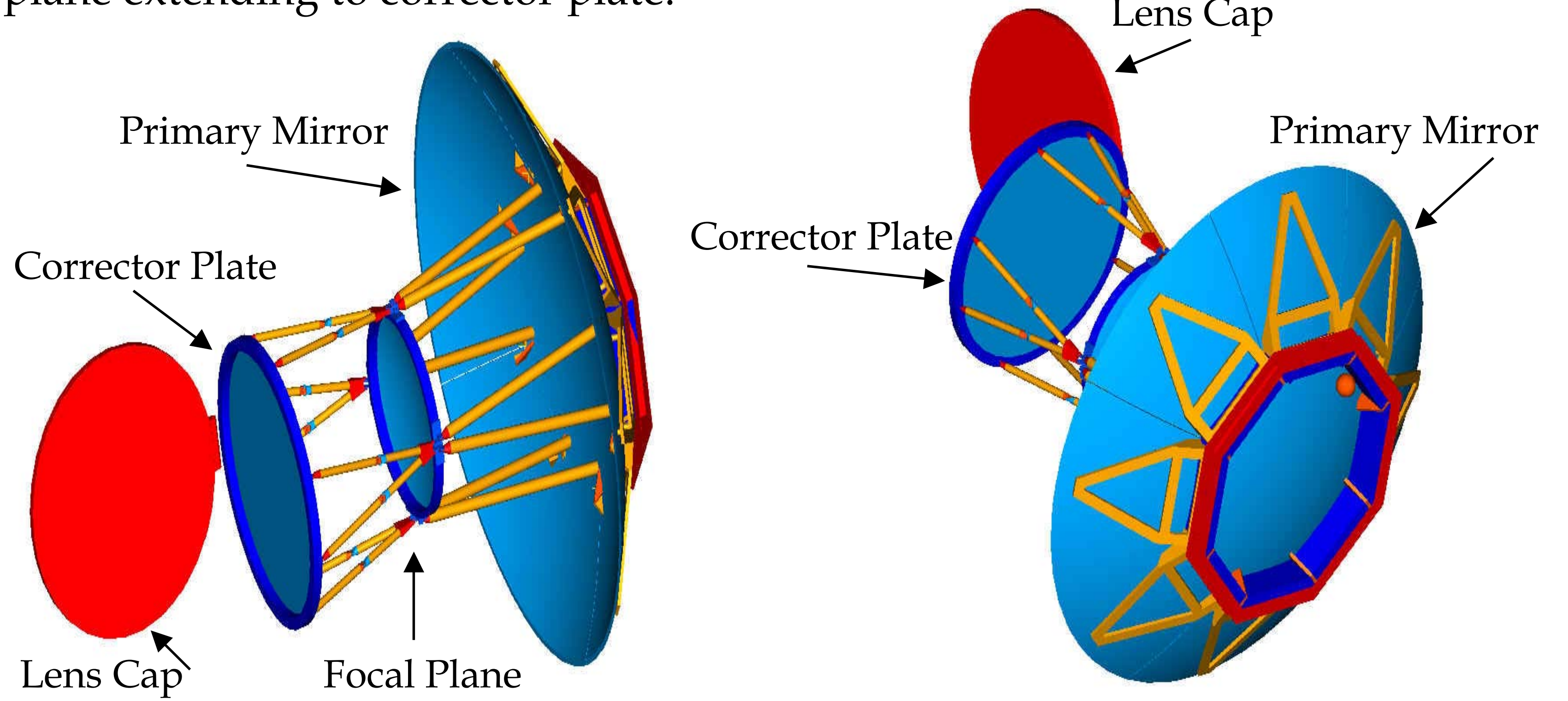
S/C roll considered to reduce thermal variations due to changes in solar beta angle. The loss of symmetry of the footprints to the track axis resulted the loss of too much overlap.

Pitch and **Roll** in degrees

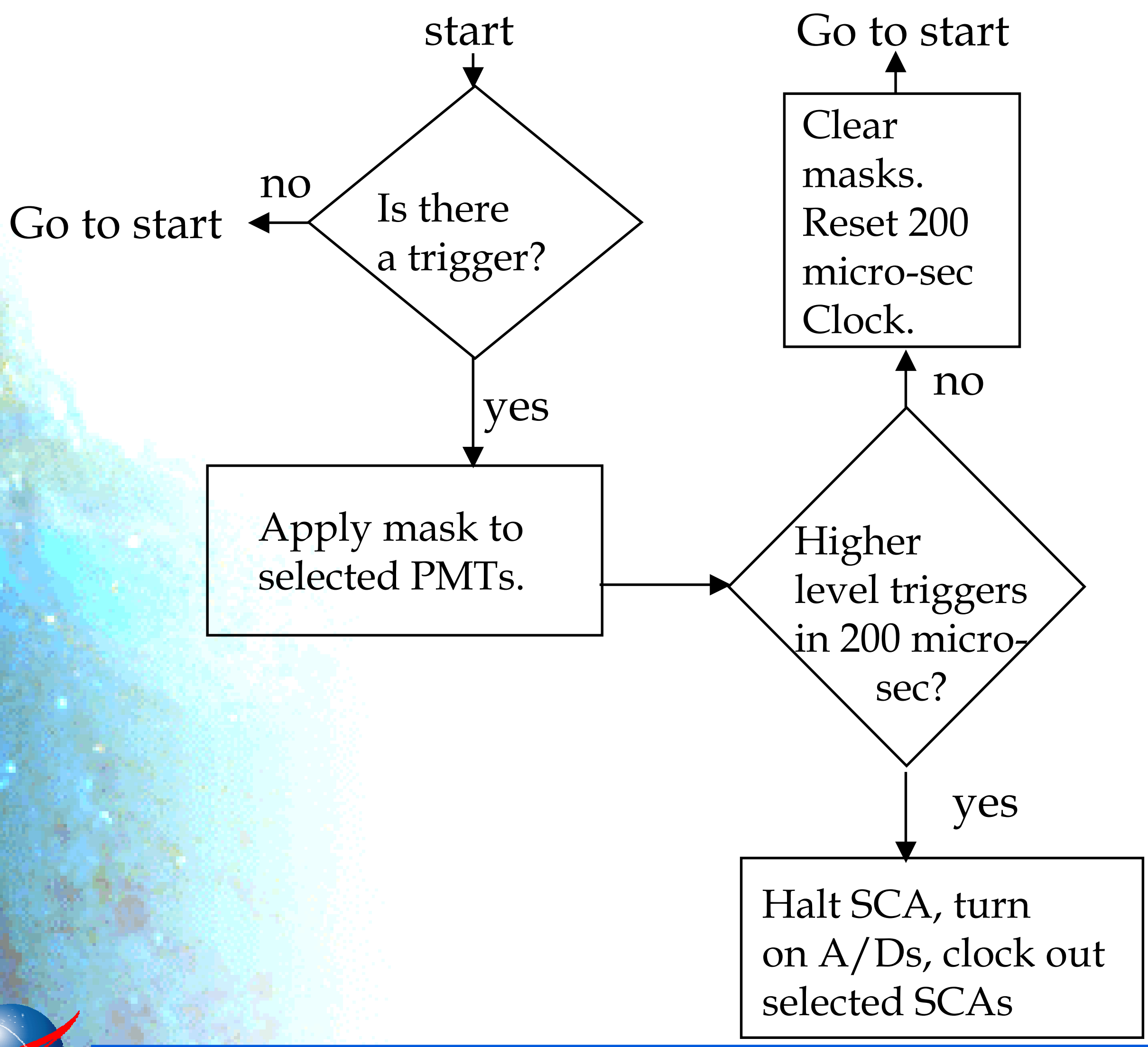


Instrument Diagram

Deployable light shield encloses primary mirror and focal plane extending to corrector plate.



Observation Sequence



Instrument Parameter Estimates

1. Mass 2000 kg

2. Power

   612 watts average

   749 watts peak

3. Data Rate 5730 bits per second

(not counting pixel address information)

Issues and Concerns

1. Instrument dimensions and mass.
2. The need to fold primary mirror.
3. Hardware required to deploy light shield.
4. Impact of adding a means to monitor clouds.
5. The large number of mechanisms required to deploy corrector plate, deploy and adjust mirror petals, and deploy light shield.

Technically, this instrument is doable. It does present engineering challenges.

Backup Slides

Requirements and Design Assumptions

Requirements and Design Assumptions			
	ISAL	**Spec**	
Near-equatorial Orbit Altitude (~ 2.5 years)	1.000E+06	1.000E+06	m
End of Mission near-equatorial orbit altitude (~0.5 years)	4.000E+05	4.000E+05	
Telescope Half Field of View	22.5	22.5	degrees
Angular Resolution	0.06	0.06	degrees
Single Photo electron sensitivity	yes	yes	
Minimum View Aperture (see note 1)	1.693E+12	1.000E+12	m^2 sr
Ability to handle atmospheric UV (300 to 400 nm) night glow (note 2)	yes	yes	
Lifetime (5 year goal)	3	3	
Approximate area of nadir look	5.390E+11	5.390E+11	m^2
Pixel size (each dimension) on the ground	1000	1000	m
Approximate number of detector pixels	539012	539012	pixels
High gain without (or before) amplification (goal 10^6)	>10^5	10^5	
Detector response time	1.00E-07	1.00E-07	sec
Independent pixel readout	yes	yes	
Cloud area and distribution (atmospheric characterization)	see note 3	yes	

Note 1: Minimum view aperture approx = (tan(HFOV)) ^2 * altitude^2 * PI^2

Note 2. Atmospheric night glow about 0.5 photo electrons per microsecond; signal ~ 7 or 8 photo electrons / microsecond @ 10^20 EV

Note 3. George Reinhardt has begun looking into this area; may be another instrument or laser which is not part of this study

Additional Instrument Trade Details

The ISAL team looked at several possible variations in the instrument design. These trade studies included:

1. Different ways of folding primary mirror for launch, several fixed primary mirrors which deployed on orbit, different diameter and field of view, with or without corrector plate.

2. Deployable versus fixed focal plane. Different ways of deploying primary mirror petals. Flat versus domed and one piece versus mosaic corrector plate. Primary mirror focus and alignment.

3. Focal plane cooling and impact on integration and test.

4. Mass and power reduction where possible.

5. Impact on science of possible S/C rolls to reduce thermal impact of solar Beta angle changes.

6. Means for determining atmospheric transmission (clouds).

Orbit Parameters

Orbit Parameters		
Earth radius **	6.371.E+06	m
Average Earth Circumference	4.003.E+07	m
Equatorial Orbit		
Orbit Height above sample altitude	**1.000E+06**	m
Average Orbit Radius	7.371E+06	m
Speed of light	2.9979E+08	m/sec
Earth Gravitational Constant = GM	3.986E+14	m^3 sec^-2
S/C Velocity (circular orbit)	**7.354E+03**	m/sec
Orbit Period	6298.0	sec
Orbit Period in minutes	**105.0**	min
Ground Track velocity	**6.356.E+03**	m/sec
Ground Track angular velocity	9.977.E-04	rad/sec
Alpha = Angle between nadir and pointing direction	45.000	degrees
Theta = angle opposite line from S/C through nadir to center of Earth	125.1054	degrees
Phi = Angle at Earth center between nadir and line from Earth center to position of laser shot on Earth surface = 180 - Alpha - Theta	9.895	degrees
R = Distance along line of site to ground	1.548E+06	m
Time from ground to S/C for signal	5.164E-03	sec
Earth Rotation velocity at equator	463	m/sec
** spherical Earth of equal volume		
* Triangle formed by satellite location, location of shot on Earth, and Earth center		
Instrument Observations		
Two instruments on two spacecraft about 500,000 meters apart. Each S/C pitches plus or minus 14 degrees (for each instrument to view the same patch of ground in the track direction between the two S/C. Observe on dark side of orbit during three day period around the time of the new moon.		

Optics and Detectors

Optics and Detectors			
Half Field of View (HFOV)	22.5	degrees	
Sensor Focal Length	3.000	m	
Entrance Aperture Diameter	3.000	m	
Primary mirror diameter	7.08	m	
Optics F Number	1.000		
optics transmission (Dennis Evans) (center of field)	0.27		
optics transmission (edge of field)	0.41		
Entrance Aperture Effective Area	7.0686	m^2	
Burle 85001 or Hamamatsu Photo Multiplier Tubes (PMTs)			
Detector array diameter	2.28E+00	m	
Detector type (photo multiplier tube)	PMT		
Number of detector elements (pixels) per PMT (approx)	400		
Percent collecting area for PMT (approx)	80	percent	
Number of detector elements (approximate)	539012		
Number of PMTs (approx)	1348		
Mass per PMT	0.100	kg	
Power requirement per PMT	0.1633	watts	
Detector element diameter	3.00E-03	m	
Detector Operational Temperature	ambient		
Approximate quantum efficiency	0.20		

Observation Sequence Details

Observation Sequence
Input from John Mitchell
1. Trigger based on input from PMT (path about three samples in space and/or time indicating possible event).
2. Apply mask to sufficient number of PMTs in vicinity of PMT that triggered to assure a radius of
about 60 pixels is covered (done to simplify lookup table).
3. Continue collecting data in Switched Capacitor Array (SCA) ring buffer (3000 deep) for 200 microseconds.
There is one sample per 100 ns. Thus ring buffer is 3000 * 100 ns = 300 microseconds long.
4. During the 200 microseconds after the initial first level trigger determine if additional higher level triggers
indicate event should be read out based on inputs in the masked region. These higher level triggers improve
selectivity. The masked area may be reduced by this process. If there is not sufficient additional indication
the event should be read out, clear the masks and cancel the 200 microsecond clock.
5. If higher level trigger requirements are made, halt SCA input clocking in masked region around event.
Turn on A/D converters for SCAs in that region. Clock out SCAs (possible low and high gain for each
pixel; 14 bit range total; ultimately final 10 bits range per pixel after all non uniformities removed).
6. Apply software triggers.
7. Apply data selection to reduce total data volume (could include geometric and temporal selection).

Instrument Data Rate

Data Rate			
Trigger rate for possible events (false events)	10	Hz	
Maximum number of expected events per day	20	per day	
Maximum track length	60000	m	
Individual sample time	1.000E-07	s	
Samples per 1000 m	33.0	samples	
Maximum samples per track length	1980	samples	
Time to sample 60000 m	1.980E-04	s	
Number of additional pixels perpendicular to an event	10	pixels	
Number of samples for real event	19800		
Output number of bits per sample	10		
Maximum number of bits per real event	198000		
Factor for overhead and housekeeping	1.25		
Real Events Data Rate (including overhead and housekeeping)	57	bits/sec	
Maximum digitization rate (using trigger rate for possible events)	2.475E+06	bits/sec	
Maximum Output Data Rate (from 10 to 100 times real data rate; includes false events)	5729	bits/sec	
Maximum Output Data rate will be increased by need for information on pixel addresses.			
Maximum Science Data Rate	**5729**	**bits/sec**	
Calibration Data Rate	**(see note 1.0)**		
Note 1. Calibration would be done on occasion on day part of orbit; would have much higher			
data rate with all pixels read out. Frequency would likely be less than once per day.			

Instrument Power Estimate

Item	Average Power (Watts)	Peak Power (Watts)	
Main Electronics Box			
Power Board	4	8	
Mech Board (on board on at a time, so peak is for board which is on)	0	4	
Mech Board	0	4	
Mech Board	0	0	
Mech Board	0	0	
Thermal control	3	3	
Housekeeping	3	3	
Processor card	4	4	
Focal Plane			
PMTs	220	220	
Digital Electronics (0.5 volt logic)	3	3	
High Voltage Power Supply	94	94	
Thermal (peak thermal related to maximum bus voltage)	30	60	
Switched Capacitor Array (SCA)	125	125	
Low Voltage Power Supply Box			
Box dissipation for focal plane digital electronics and SCA	55	55	
Mechanisms	1	40	
Thermal heaters			
Corrector Plate	20	36	
Telescope	50	90	
Instrument Power	**612**	**749**	**watts**
Survival power = 300 watts			
Turn on loop heat pipes (6 @ 50 watts each = 300 watts)			
Example of peak power is operation of four HOP actuators @ 10 watts each			

Instrument Mass Estimate

Instrument Synthesis and Analysis Laboratory

Instrument Mass Estimates				
Item	**Each (kg)**	**Number**	**Mass (kg)**	
Corrector Plate (160 kg * 1.25 for individual lens frames)			200.0	
Structure for Corrector Plate			50.0	
Drives and latches for Corrector Plate			12.0	Est.
Lens cap (includes brackets, motor, latches)			50.0	
Primary Mirror petals	35.0	9	315.0	
Primary mirror petal support structures	14.0	8	112.0	
Primary Mirror mechanisms			20.0	
Primary mirror interface and S/C mounting structure			134.0	
Focal plane assembly PMTs	0.1	1348	134.8	
Focal plane assembly structure and supports (7.5 kg each tube + 6.5 kg fittings for each tube)			402.0	
Focal plane high voltage power supply (100 PMTs per supply)	1.5	14	21.0	
Focal plane electronics				
Light shield pressure tank			31.7	
Light and debris shield			98.5	
Light shield plumbing (total light shield system = 150 kg)			19.8	
Fasteners, misc mech			200.0	
Main Electronics Box			7.0	
Focal Plane Assembly Low Power Instrument Power Distribution box			5.0	
Mounts, mechanisms for lens cap			8.0	
Cabling, misc electrical			10.0	Est
Focal plane heat pipes	0.25	15	3.8	
Radiators (includes S/C)	23.0	2	46.0	
Loop heat pipes (with condensers and evaporators)	4.0	6	24.0	
Passive thermal conductors from back of focal plane to heat pipe plane			30.0	
Other thermal hardware (blankets, heaters, coatings, saddles)			30.0	
		TOTAL	**1,964.5**	**kg**

Pitch and Roll Calculations

P-Angle = pitch angle	**-14.0**	degrees	Positive pitch angle goes with zero ground reference for X (lead S/C)
R-Angle = roll angle	**23.5**	degrees	
HFOV = half angle Field of View	**22.5**	degrees	

Distance between the two spacecraft nadir positions **-627164** m (could try increasing this distance, but loss of overlap would still be significant)

Note: computed distance between nadir points for two S/C with plus or minus 14 degree pitches, 22.5 degree HFOV, and 0 degree roll based on overlapping footprints. Nadir point for second S/C equaled **- 627164 m** relative to lead S/C**.**

H = orbit height **1.000E+06** m

RE = Earth Radius 6.371E+06 m

Alpha = angle between pointing direction and nadir

Theta = angle opposite side of triangle which includes RE + H

Phi = Earth central angle between line to S/C and line to point of intersection on Earth surface for pointing from S/C

Beta = Azimuth angle from track direction; 0 degrees = track direction; clockwise when viewed from above S/C XY plane

X = track direction; Y = xtrack; Z =0 at Earth surface, positive Z in zenith direction

I,j,k = unit vectors in pointing direction from S/C to Earth surface with instrument pointing to nadir

Cosine(Alpha) = nadir direction dot pointing angle

sin(Theta) = (RE+H) /RE * sin(Alpha); Theta = asin((RE+H)/RE*sin(Alpha))

Beta angle increment = 15 degrees

P-Angle = pitch angle = angle of rotation about Y axis

R-Angle = roll angle = angle of rotation about X axis

Nadir global track position (for second spacecraft (S/C)) = distance from nadir ground point of first S/C to nadir ground point of second S/C.

Track component pointing position for second S/C = Nadir global track position plus track local position

Y Rotation matrix = Pitch Matrix

cos(P-Angle)	0	-sin(P-Angle)
0	1	0
sin(P-Angle)	0	cos(P-Angle)

ip = (a*cos(P-Angle) + c*sin(PAngle)) I

jp = b j

kp = (-a*sin(P-Angle) + c*cos(P-Angle) k

X Rotation matrix = Roll Matrix

1	0	0
0	cos(R-Angle)	sin(R-Angle)
0	-sin(R-Angle)	cos(R-Angle)

ir = a I

jr = (b*cos(Alpha) - c*sin(Alpha)) j

kr = (b*sin(Alpha) + c*cos(Alpha) k

Pitch and Roll Calculations 2

Beta	I	j	k	ip	jp	kp	ir	jr	kr	unit
0	0.38268	0.00000	-0.92388	0.59482	0.00000	-0.80386	0.59482	0.320537	-0.737185	1.00000
15	0.36964	-0.09905	-0.92388	0.58217	-0.09905	-0.80701	0.58217	0.230964	-0.779572	1.00000
30	0.33141	-0.19134	-0.92388	0.54508	-0.19134	-0.81626	0.54508	0.150011	-0.824857	1.00000
45	0.27060	-0.27060	-0.92388	0.48607	-0.27060	-0.83097	0.48607	0.083195	-0.869953	1.00000
60	0.19134	-0.33141	-0.92388	0.40916	-0.33141	-0.85015	0.40916	0.035069	-0.911786	1.00000
75	0.09905	-0.36964	-0.92388	0.31961	-0.36964	-0.87248	0.31961	0.008913	-0.947507	1.00000
90	0.00000	-0.38268	-0.92388	0.22351	-0.38268	-0.89644	0.22351	0.006509	-0.974681	1.00000
105	-0.09905	-0.36964	-0.92388	0.12740	-0.36964	-0.92040	0.12740	0.028022	-0.991455	1.00000
120	-0.19134	-0.33141	-0.92388	0.03785	-0.33141	-0.94273	0.03785	0.071985	-0.996687	1.00000
135	-0.27060	-0.27060	-0.92388	-0.03905	-0.27060	-0.96190	-0.03905	0.135402	-0.990021	1.00000
150	-0.33141	-0.19134	-0.92388	-0.09806	-0.19134	-0.97661	-0.09806	0.213952	-0.97191	1.00000
165	-0.36964	-0.09905	-0.92388	-0.13516	-0.09905	-0.98586	-0.13516	0.30228	-0.943588	1.00000
180	-0.38268	0.00000	-0.92388	-0.14781	0.00000	-0.98902	-0.14781	0.394369	-0.906987	1.00000
195	-0.36964	0.09905	-0.92388	-0.13516	0.09905	-0.98586	-0.13516	0.483942	-0.8646	1.00000
210	-0.33141	0.19134	-0.92388	-0.09806	0.19134	-0.97661	-0.09806	0.564895	-0.819315	1.00000
225	-0.27060	0.27060	-0.92388	-0.03905	0.27060	-0.96190	-0.03905	0.631711	-0.774219	1.00000
240	-0.19134	0.33141	-0.92388	0.03785	0.33141	-0.94273	0.03785	0.679837	-0.732386	1.00000
255	-0.09905	0.36964	-0.92388	0.12740	0.36964	-0.92040	0.12740	0.705993	-0.696665	1.00000
270	0.00000	0.38268	-0.92388	0.22351	0.38268	-0.89644	0.22351	0.708397	-0.669491	1.00000
285	0.09905	0.36964	-0.92388	0.31961	0.36964	-0.87248	0.31961	0.686884	-0.652717	1.00000
300	0.19134	0.33141	-0.92388	0.40916	0.33141	-0.85015	0.40916	0.642921	-0.647485	1.00000
315	0.27060	0.27060	-0.92388	0.48607	0.27060	-0.83097	0.48607	0.579504	-0.654151	1.00000
330	0.33141	0.19134	-0.92388	0.54508	0.19134	-0.81626	0.54508	0.500955	-0.672262	1.00000
345	0.36964	0.09905	-0.92388	0.58217	0.09905	-0.80701	0.58217	0.412626	-0.700584	1.00000
360	0.38268	0.00000	-0.92388	0.59482	0.00000	-0.80386	0.59482	0.320537	-0.737185	1.00000

Pitch and Roll Calculations 3

Beta	Alpha (degrees)	Theta (degrees)	Phi (degrees)	Normalize ir	Normalize jr	Track Phi (degrees)	Xtrack Phi (degrees)	Local Track Location (m)	Global Track Location (m)	XTrack Location (m)	Normalize ir and jr
0	42.508	128.579	8.913	0.880	0.474	7.846	4.228	872475	245311	470158	1.0000
15	38.779	133.563	7.659	0.930	0.369	7.119	2.824	791577	164413	314042	1.0000
30	34.426	139.150	6.424	0.964	0.265	6.194	1.705	688687	61523	189535	1.0000
45	29.547	145.212	5.241	0.986	0.169	5.166	0.884	574410	-52754	98316	1.0000
60	24.247	151.633	4.121	0.996	0.085	4.106	0.352	456535	-170629	39129	1.0000
75	18.647	158.289	3.064	1.000	0.028	3.063	0.085	340551	-286613	9497	1.0000
90	12.921	165.007	2.072	1.000	0.029	2.071	0.060	230318	-396846	6708	1.0000
105	7.496	171.320	1.185	0.977	0.215	1.157	0.255	128685	-498479	28304	1.0000
120	4.665	174.601	0.734	0.465	0.885	0.342	0.650	37995	-589169	72264	1.0000
135	8.101	170.617	1.282	-0.277	0.961	-0.355	1.232	-39513	-666677	136997	1.0000
150	13.612	164.199	2.188	-0.417	0.909	-0.912	1.989	-101390	-728554	221212	1.0000
165	19.337	157.475	3.189	-0.408	0.913	-1.302	2.911	-144725	-771889	323679	1.0000
180	24.908	150.839	4.253	-0.351	0.936	-1.493	3.983	-165979	-793143	442848	1.0000
195	30.163	144.456	5.381	-0.269	0.963	-1.447	5.183	-160949	-788113	576292	1.0000
210	34.984	138.445	6.571	-0.171	0.985	-1.124	6.474	-124972	-752136	719907	1.0000
225	39.266	132.924	7.811	-0.062	0.998	-0.482	7.796	-53590	-680754	866842	1.0000
240	42.913	128.023	9.064	0.056	0.998	0.504	9.050	56023	-571141	1006285	1.0000
255	45.840	123.901	10.259	0.178	0.984	1.822	10.096	202582	-424582	1122593	1.0000
270	47.972	120.749	11.279	0.301	0.954	3.394	10.756	377354	-249810	1196010	1.0000
285	49.253	118.775	11.972	0.422	0.907	5.051	10.854	561590	-65574	1206930	1.0000
300	49.648	118.152	12.200	0.537	0.844	6.550	10.292	728341	101177	1144444	1.0000
315	49.145	118.945	11.910	0.643	0.766	7.654	9.125	851077	223913	1014681	1.0000
330	47.758	121.073	11.169	0.736	0.677	8.224	7.558	914431	287267	840412	1.0000
345	45.526	124.353	10.120	0.816	0.578	8.257	5.852	918121	290957	650739	1.0000
360	42.508	128.579	8.913	0.880	0.474	7.846	4.228	872475	245311	470158	1.0000

Optics Transmission

Optics Transmission				
	Each Surface	Number of Surfaces	Center of Field	Edge of Field
Spectral filter (300 to 400 nm transmitted)			0.900	0.900
Primary Mirror			0.95	0.95
Corrector Plate	0.98	2	0.9604	0.9604
Corrector plate obscuration (transmission)			0.95	0.95
Focal plane obscuration (transmission)			0.430	0.649
Worse case detector active area			0.8	0.8
Optics Transmission			0.27	0.41